INL/MIS-19-54054-Revision-0

# Fission Gas Monitoring for the AGR-5/6/7 Experiment

Dawn M Scates

May 2019

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operated by Battelle Energy Alliance

Idaho National Laboratory

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**May 2019**

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**Idaho Falls, Idaho 83415**

**http://www.inl.gov**

**Prepared for the**
**U.S. Department of Energy**

**Under DOE Idaho Operations Office**
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# Program Goals and Objectives

# Accomplishments Since May 2018

# FY-2019
# Level 2 and 3 Milestone Status

# Path Forward

# Fission Gas Monitoring for the AGR-5/6/7 Experiment


- Advanced Reactor Technologies
- Idaho National Laboratory

## D.M. Scates, E.L. Reber, R.G. Fronk

## Presented by R.G. Fronk

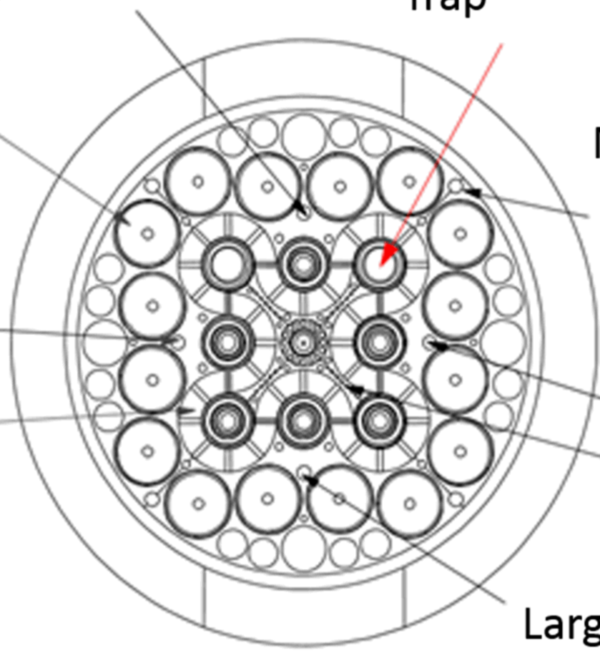

Gas-Cooled Reactor
Fuels and Methods Program Review
June 18-19, 2019

ART
ADVANCED REACTOR TECHNOLOGIES

# Outline

- What is AGR-5/6/7?
  - Location
  - Mission
- What is the Fission Product Monitoring System (FPMS)?
- Initial FPMS Start Up
  - Line Volume Determination
- AGR-5/6/7 Data Collection
- Continuing work
- Conclusion

# ATR Core Cross-section




The NEFT has higher fast fluence (4.4 x $10^{14}$ n/cm$^2$/s) and thermal (1.1 x $10^{14}$ n/cm$^2$/s) neutron flux, which allow irradiations to achieve the burnup and fast neutron fluence requirements in a shorter period of time (i.e., approximately 20 to 24 months versus 30 to 36 months in a Large B position).

# AGR-5/6/7 Objectives

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- The AGR-5/6/7 experiment is a combination of three tests from the early program plan.
- These tests serve as the formal fuel qualification irradiations (AGR-5/6) and the margin test (AGR-7).
- The purpose of the margin test is to demonstrate that there is a margin between the highest fuel temperature in an operating high temperature gas reactor (HTGR) and the temperature at which fuel particle failure rate becomes unacceptable.

The primary mission for AGR-5/6/7 is to support fuel qualification for the Nuclear Regulatory Commission (NRC), accomplish fuel margin testing (AGR-7), and pilot scale fuel fabrication capabilities.

# AGR-5/6/7 Fuel Parameters

| Capsule | No. of Particles | Packing Fraction |
|---|---|---|
| 1 | 309,060 | 40% |
| 2 | 72,448 | 25% |
| 3 | 54,360 | 25% |
| 4 | 52,728 | 25% |
| 5 | 81,432 | 40% |

**AGR Temperature Goals**

**AGR-5/6: The time average temperature distribution goals:**

- ≥ 600°C - < 900°C for 30% of the fuel
- ≥ 900°C - <1050°C for 30% of the fuel
- ≥1050°C - <1250°C for 30% of the fuel
- ≥1250°C - <1400°C for 10% of the fuel

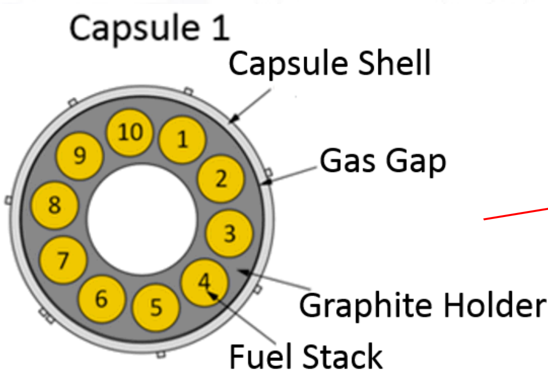
**AGR-7 (Capsule 3): The time average, peak temperature:**

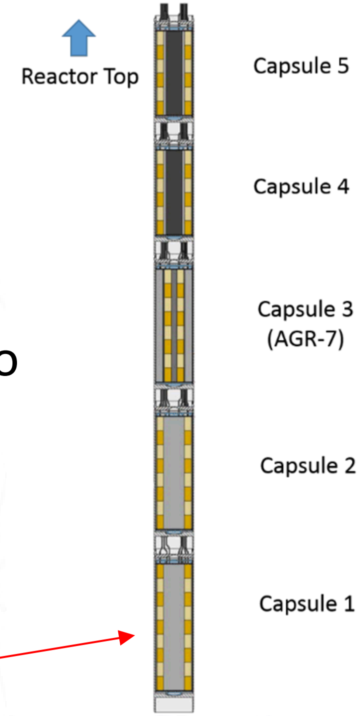
- 1350± 50°C - 1500 ± 50°C

- TRISO-particle fuel in the form of cylindrical compacts.
- Nominally 25.0mm in length and 12.3 mm in diameter.
- 194 compacts distributed within 5 capsules that contain a U-235 content of 35.7 grams and total uranium content of 230.3 grams.
- The particles are UCO low enriched uranium (LEU) fuel kernels with an enrichment level of 15.5wt%.
- The TRISO over-coating process yields AGR-5/6/7 fuel particles that have 870-µm nominal diameter.
- Number of particles per capsule are obtained by dividing the uranium mass content of a compact by the uranium mass content of a particle.

# AGR-5/6/7 Capsule 1

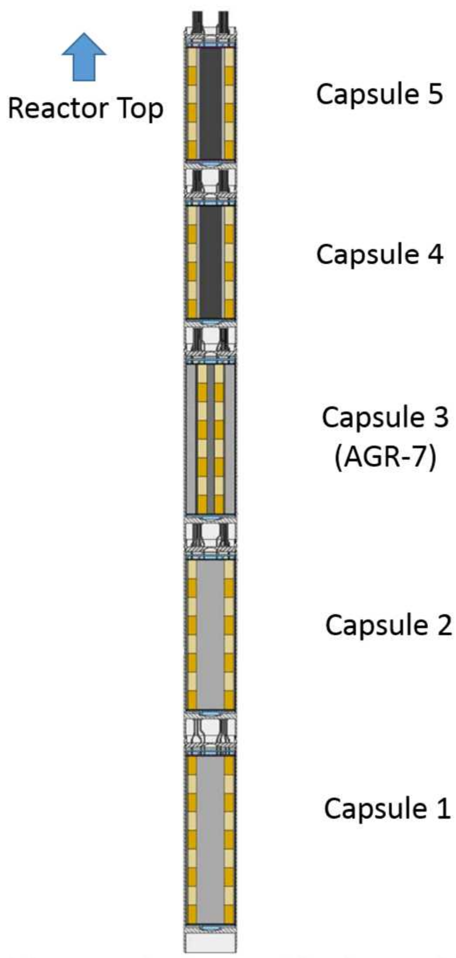
- Bottom capsule in test train
- Contains ten fuel stacks (90 compacts)
- A hollow center to reduce total energy deposition
- 228.6mm long
- No thru-tubes
- Capsule 1 is completely sealed which means there is no cross-talk between capsule 1 and the other capsules



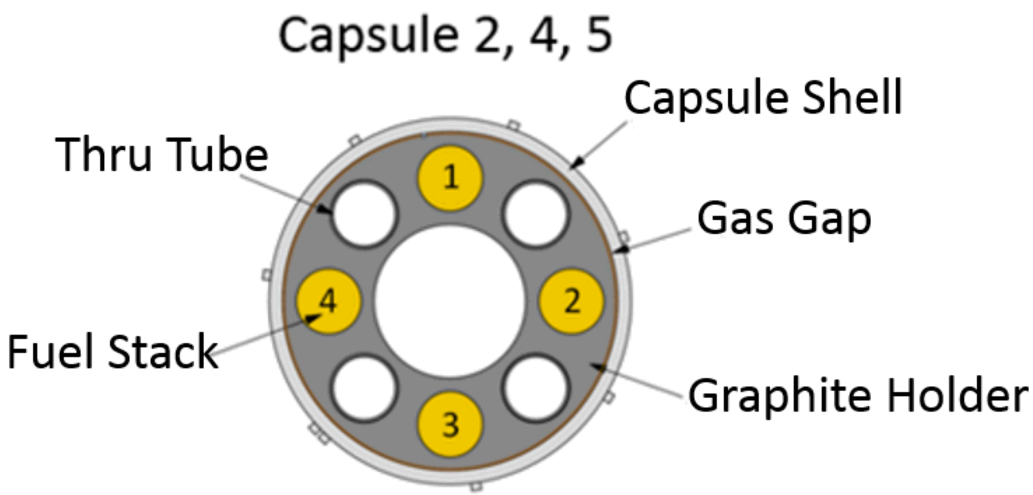




With no thru-tubes there is more room for fuel stacks and, therefore, capsule 1 contains the most fuel (60%) of the AGR-5/6 capsules.

# AGR-5/6/7 Capsules 2, 4 and 5

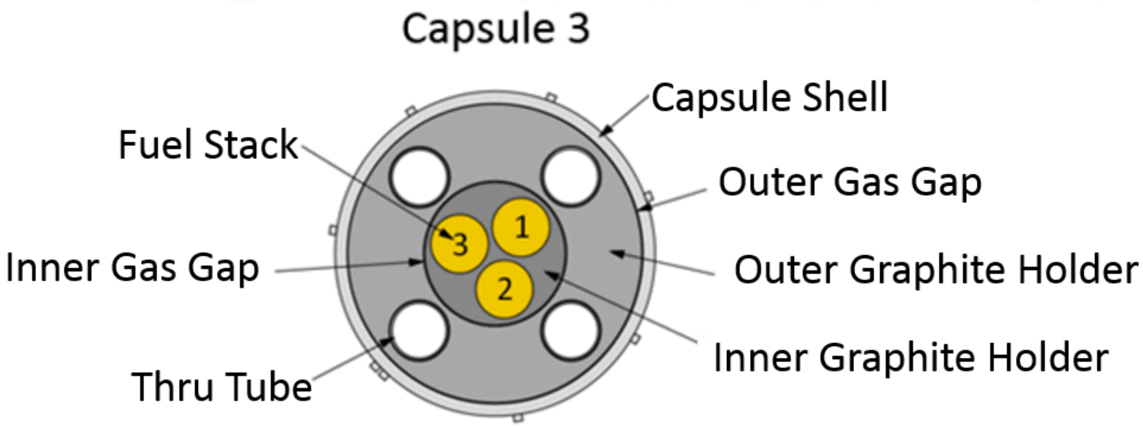


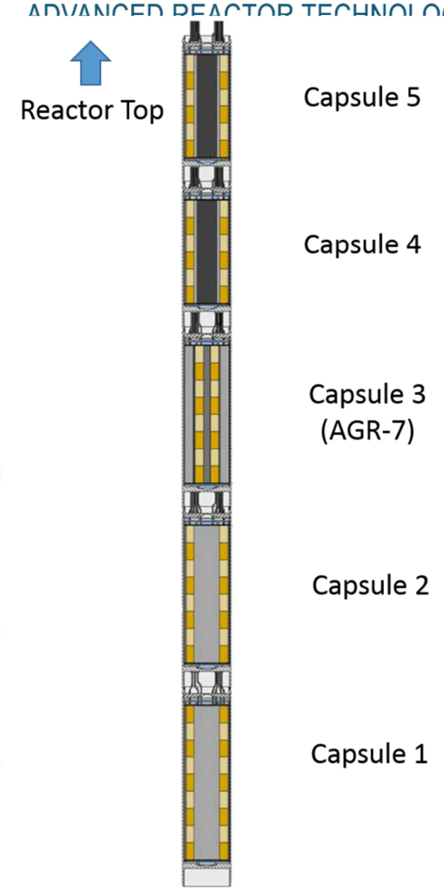

- Four fuel stacks each and like Capsule 1, contains hollow centers
- Capsule 2 contains 32 compacts and is 203.2mm in length
- Capsules 4 and 5 each contain 24 compacts and are 152.4mm in length



# AGR-5/6/7 Capsule 3

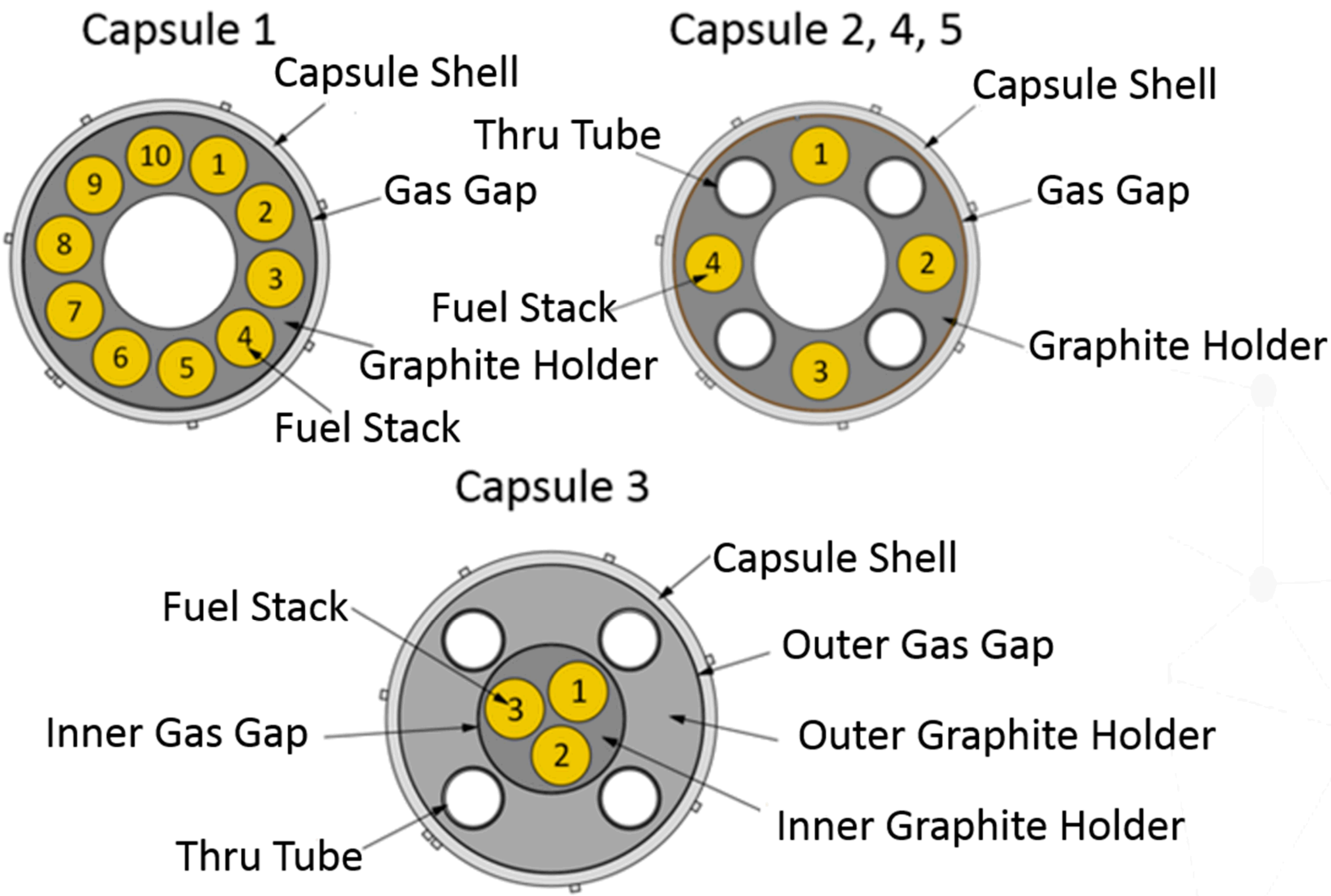
- Capsule 3 is the AGR-7 margin test
- Three fuel stacks consisting of a total of 24 compacts
- 203.2 mm inches in length



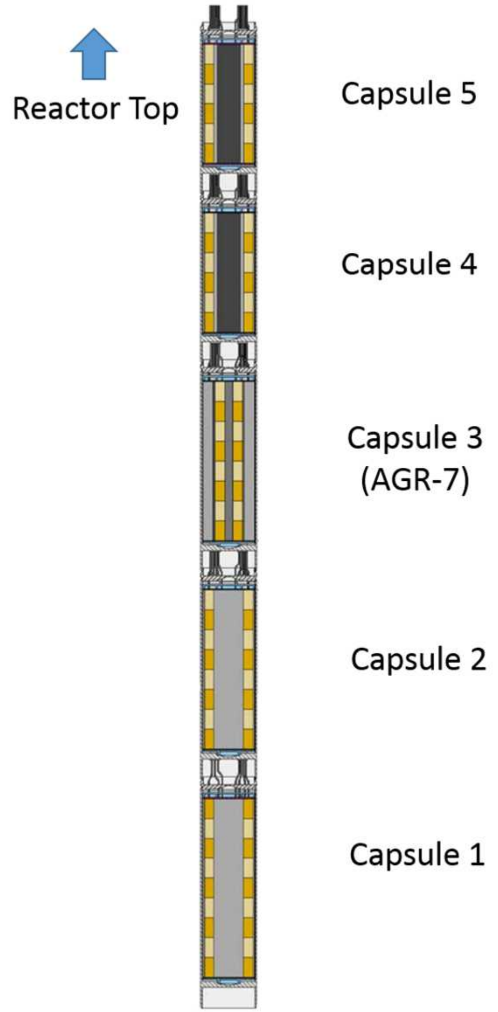




Capsule 3 contains a unique design feature in that the graphite holder has been separated into two pieces, allowing the center mass to run hot while keeping the thru-tubes relatively cool, thereby extending the life of the instrumentation lines contained within the thru-tubes.

# AGR-5/6/7 Capsule Cross Section Summary



# AGR-5/6/7 Uniqueness



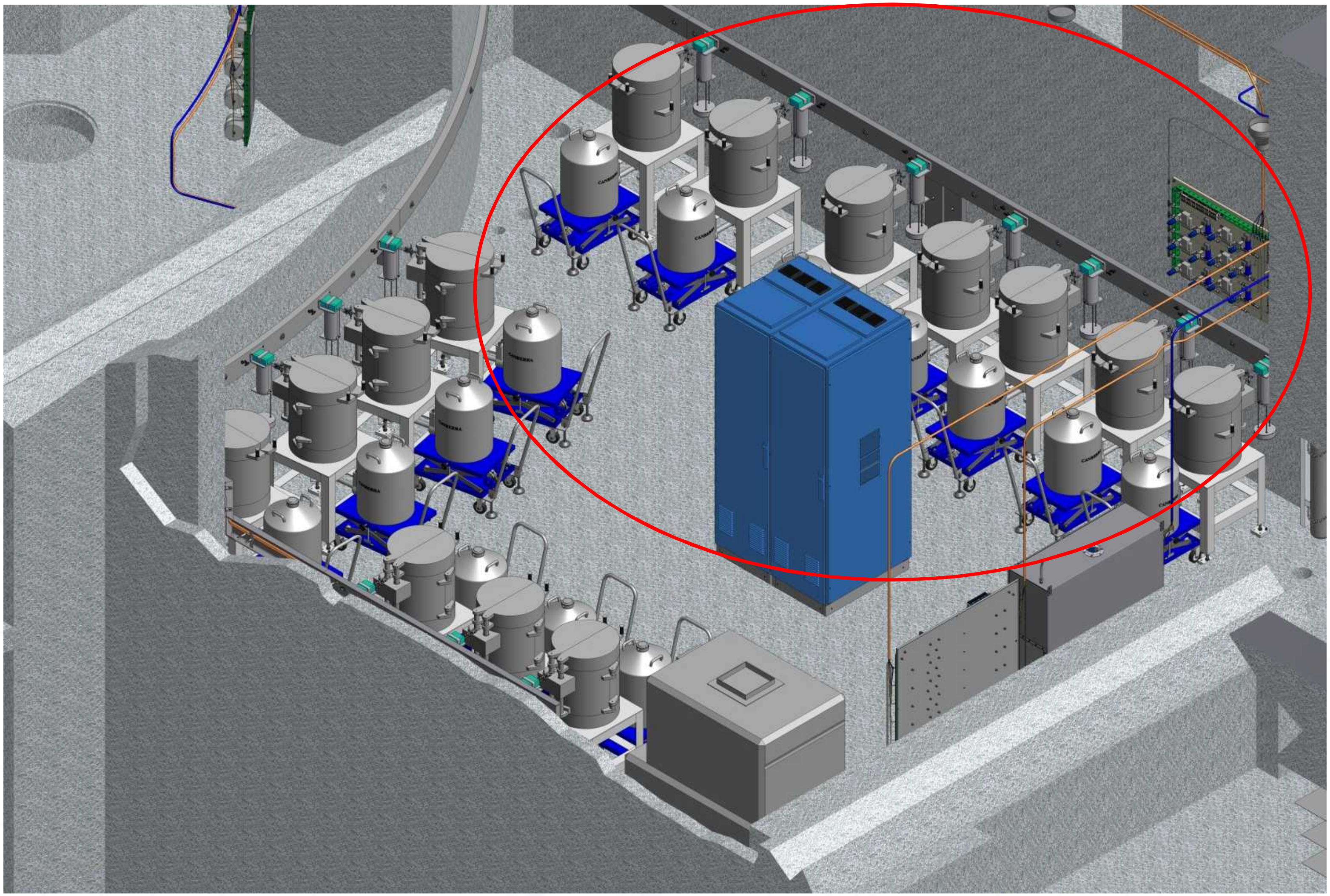

- AGR-5/6/7 was designed to stay in the reactor for high power runs.
- Contains more thermocouples than any other AGR experiment - 54!

| Capsule | Number of TC's |
|---|---|
| 1 | 17 |
| 2 | 8 |
| 3 | 17 |
| 4 | 6 |
| 5 | 6 |

- Self-Powered Neutron Detector (SPND) located in capsules 2, 3, 4 and 5.
- One Micro-Pocket Fission Detector (MPFD) in capsule 5.
- One ultrasonic temperature sensor (capsule 5) and
- Two fiber-optic temperature sensors also located in capsule 5.

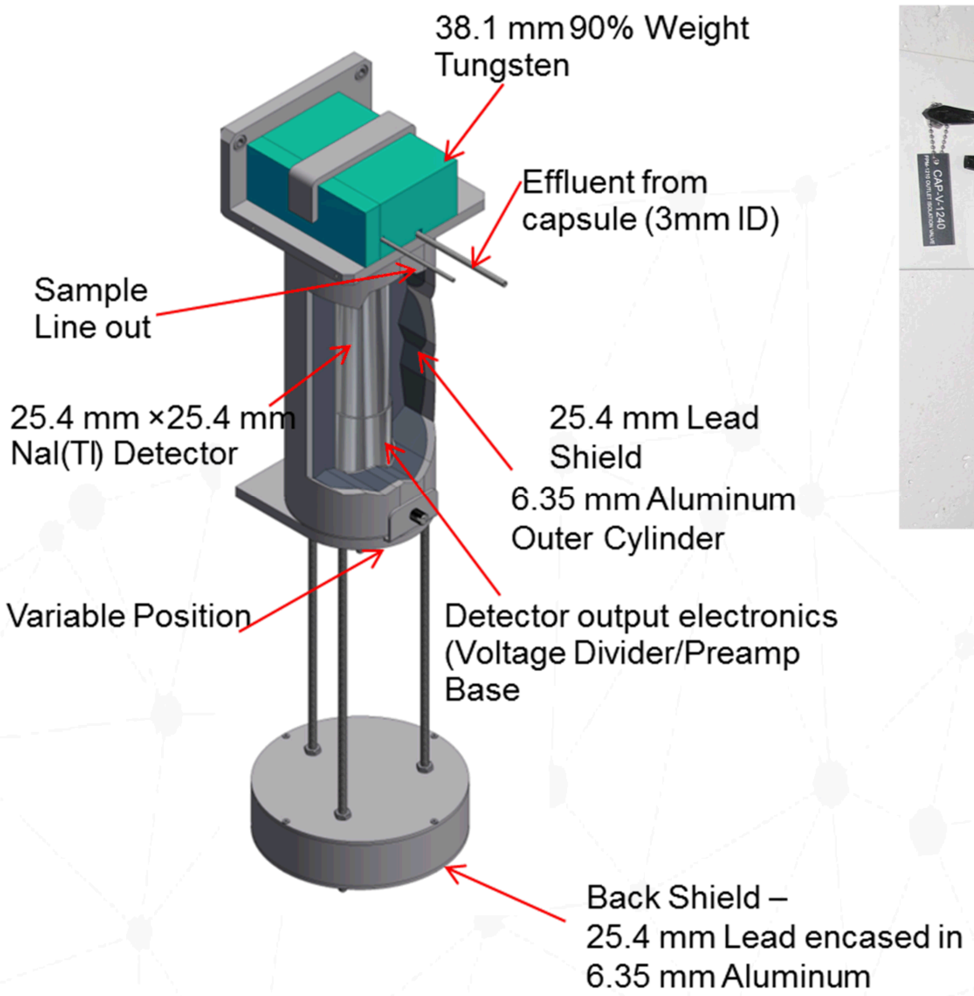
# AGR-5/6/7 Installation into the ATR

# Fission Product Monitoring System (FPMS)

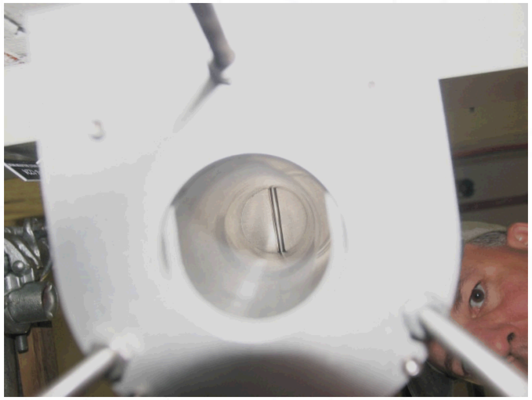


# Gross Monitor System

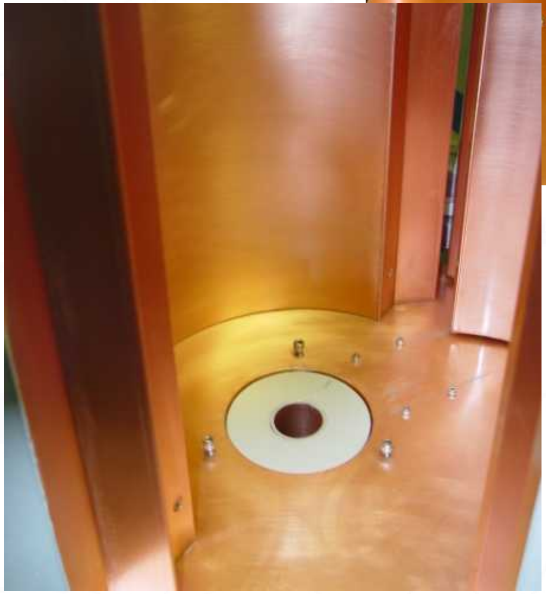




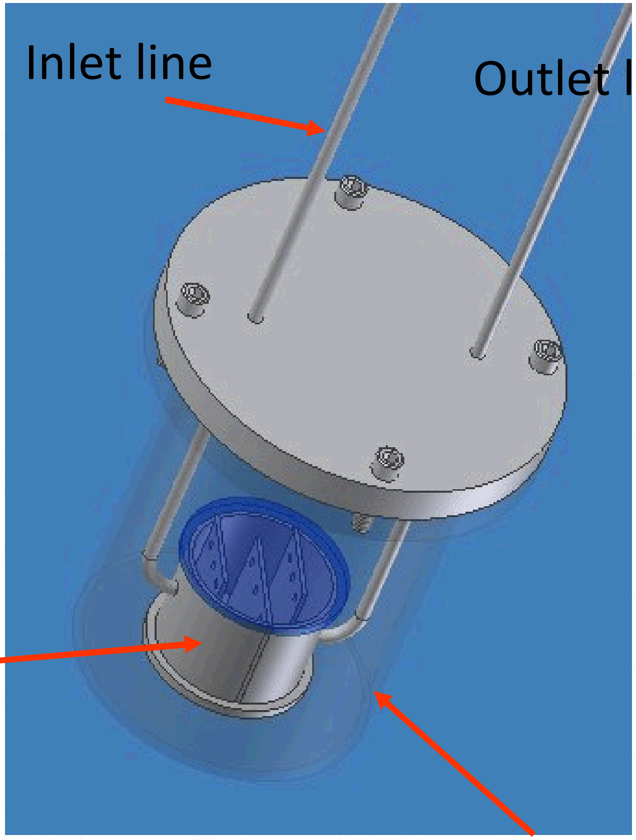


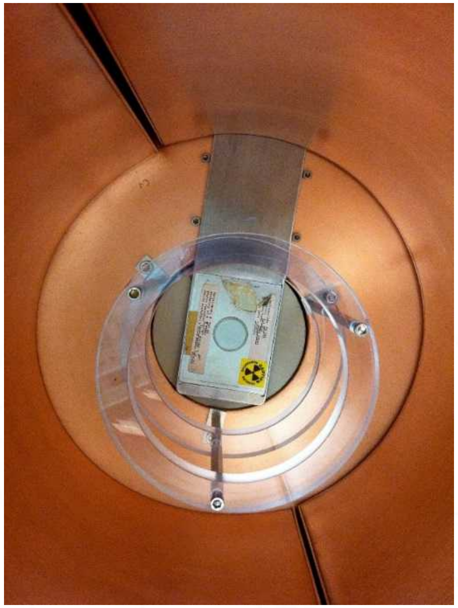
# FPMS – Gamma Ray Spectrometer System



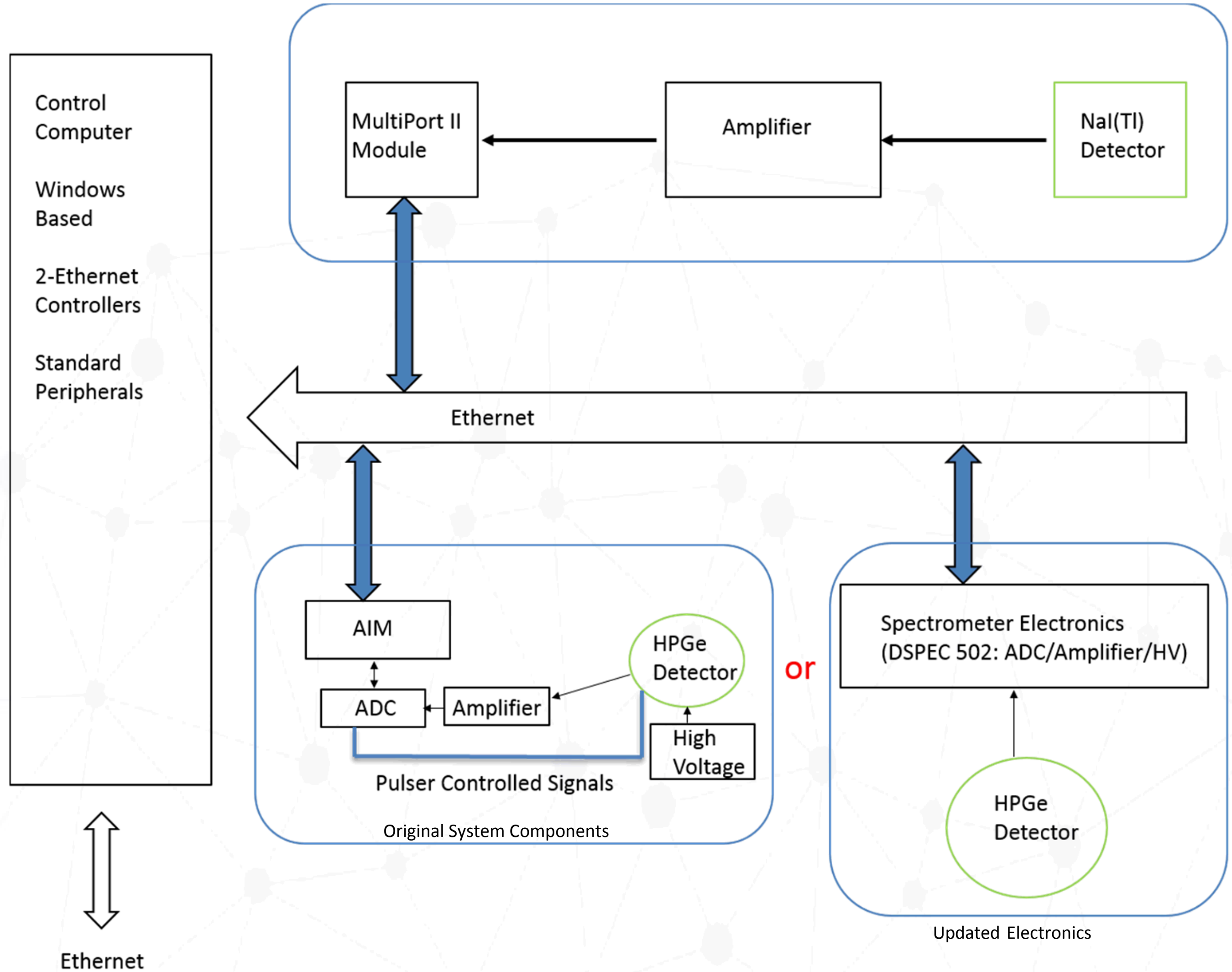
# FPMS – Gamma Ray Spectrometer System (cont.)



# System Calibration



# FPMS Block Diagram

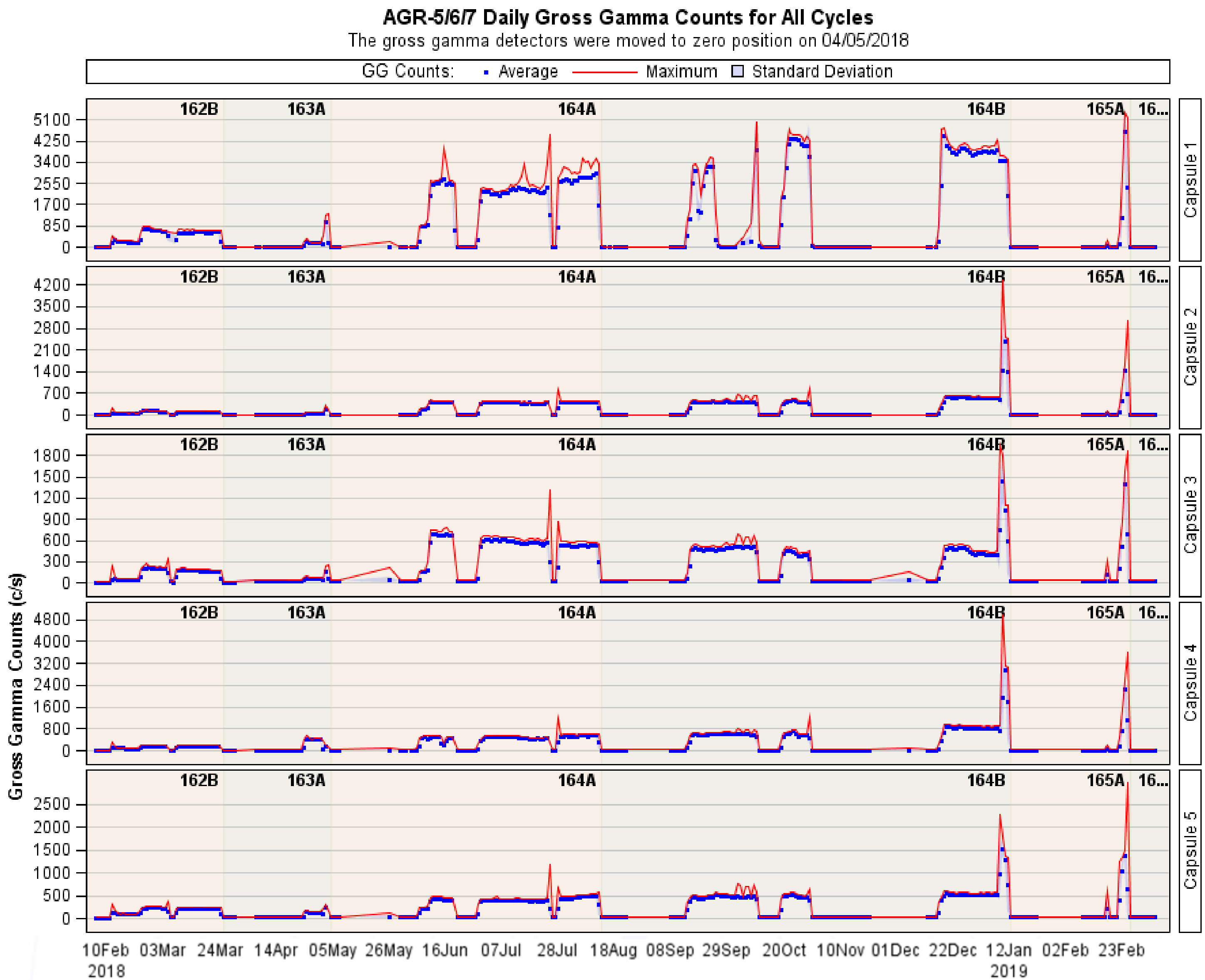


# FPM – Data Reprocessing, Analysis and Auxiliary Programs

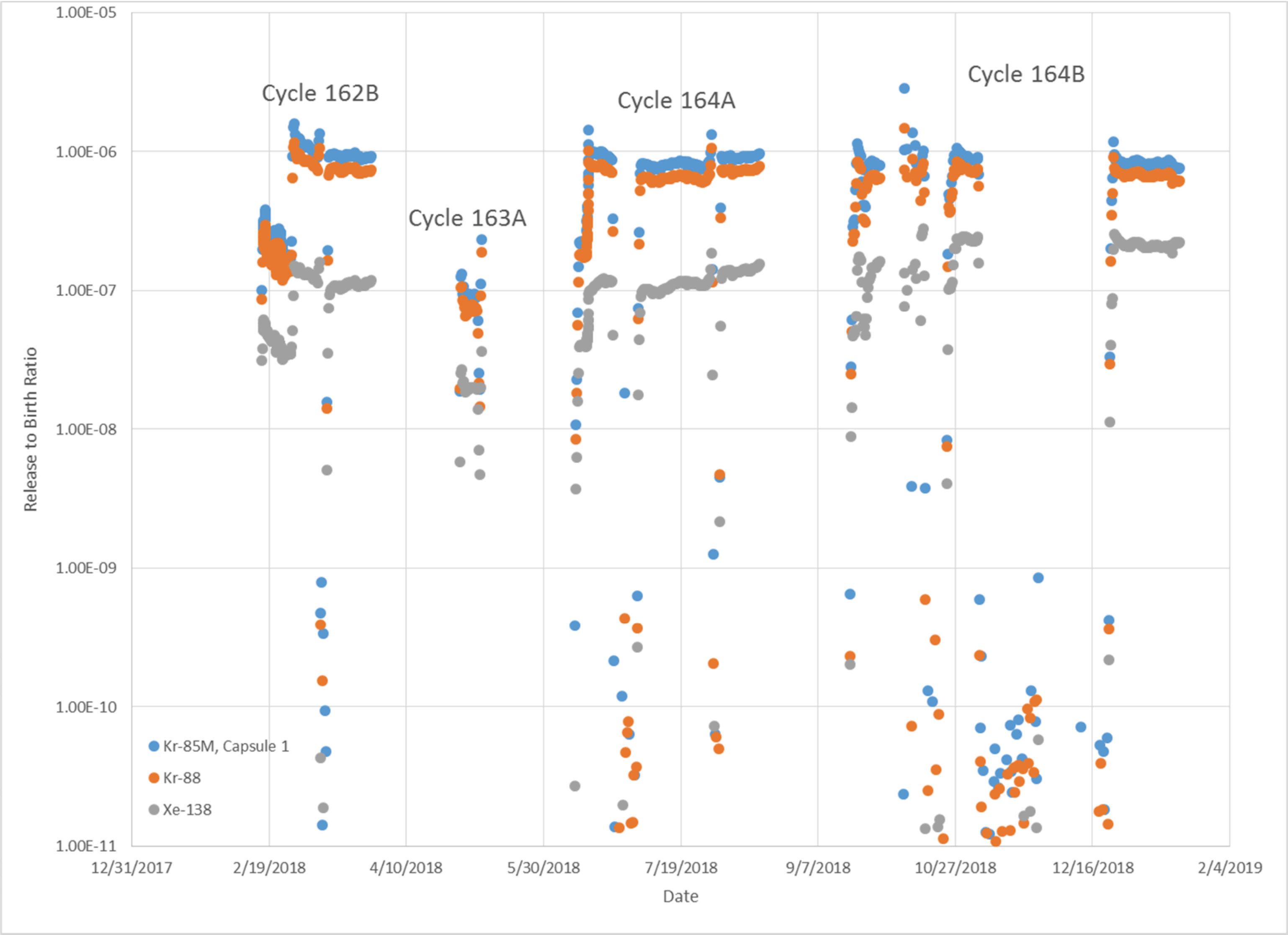

| Isotope: | |
|---|---|
| Kr-85m | Xe-131m |
| Kr-87 | Xe-133 |
| Kr-88 | Xe-135 |
| Kr-89 | Xe-135m |
| Kr-90 | Xe-137 |
| | Xe-138 |
| | Xe-139 |

Isotopes were selected because the half-life for each isotope is short enough to enable the inventory to reach equilibrium within the fuel. Optimal half lives for the AGR-5/6/7 experiment range from 30 seconds to less than 10 hours.

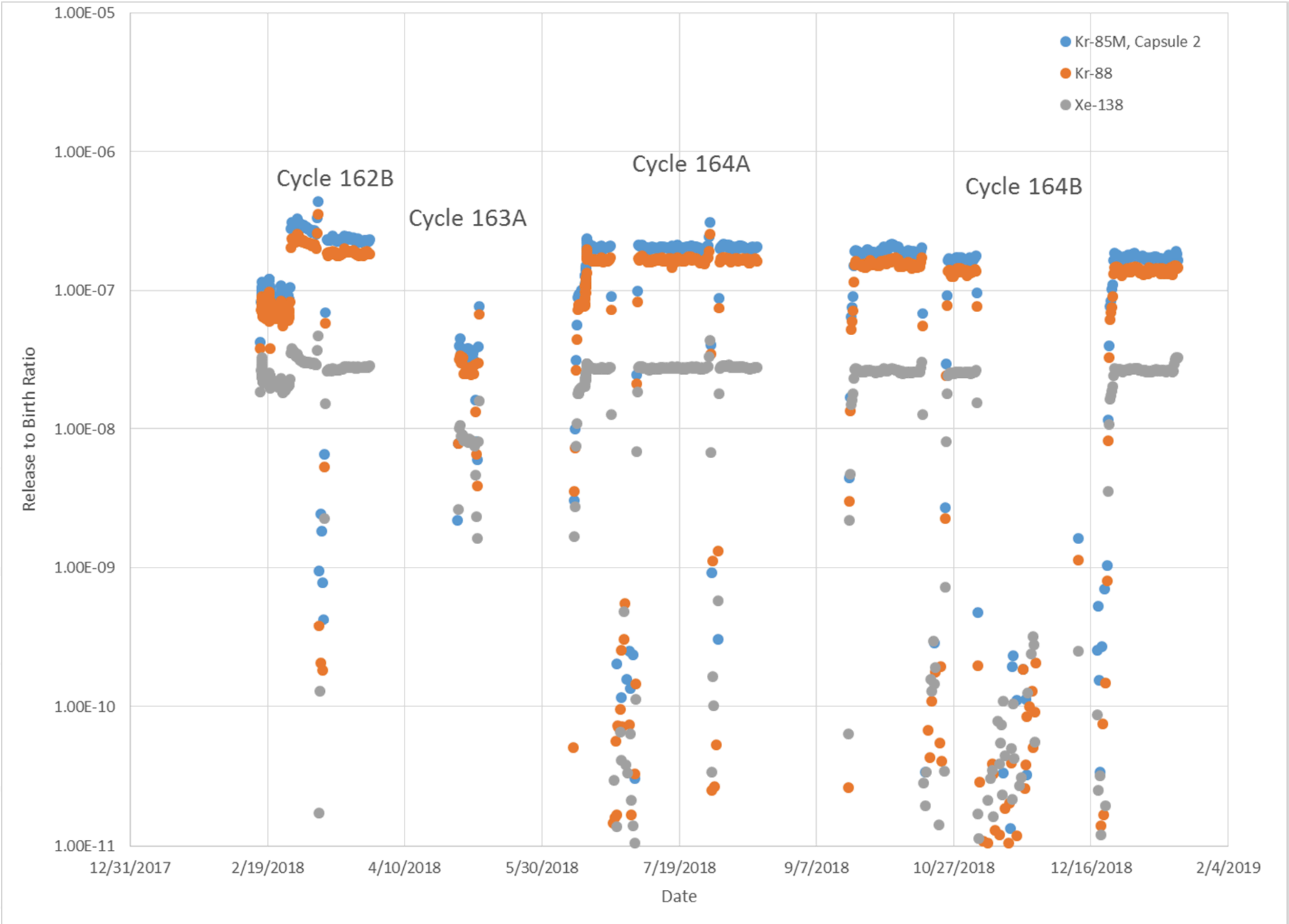
# Summary of Gross Gamma Data



# Preliminary R/B – First Four Cycles-Capsule 1 (40%PF)



# Preliminary R/B – First Four Cycles-Capsule 2



# Preliminary R/B – First Four Cycles- Capsule 3

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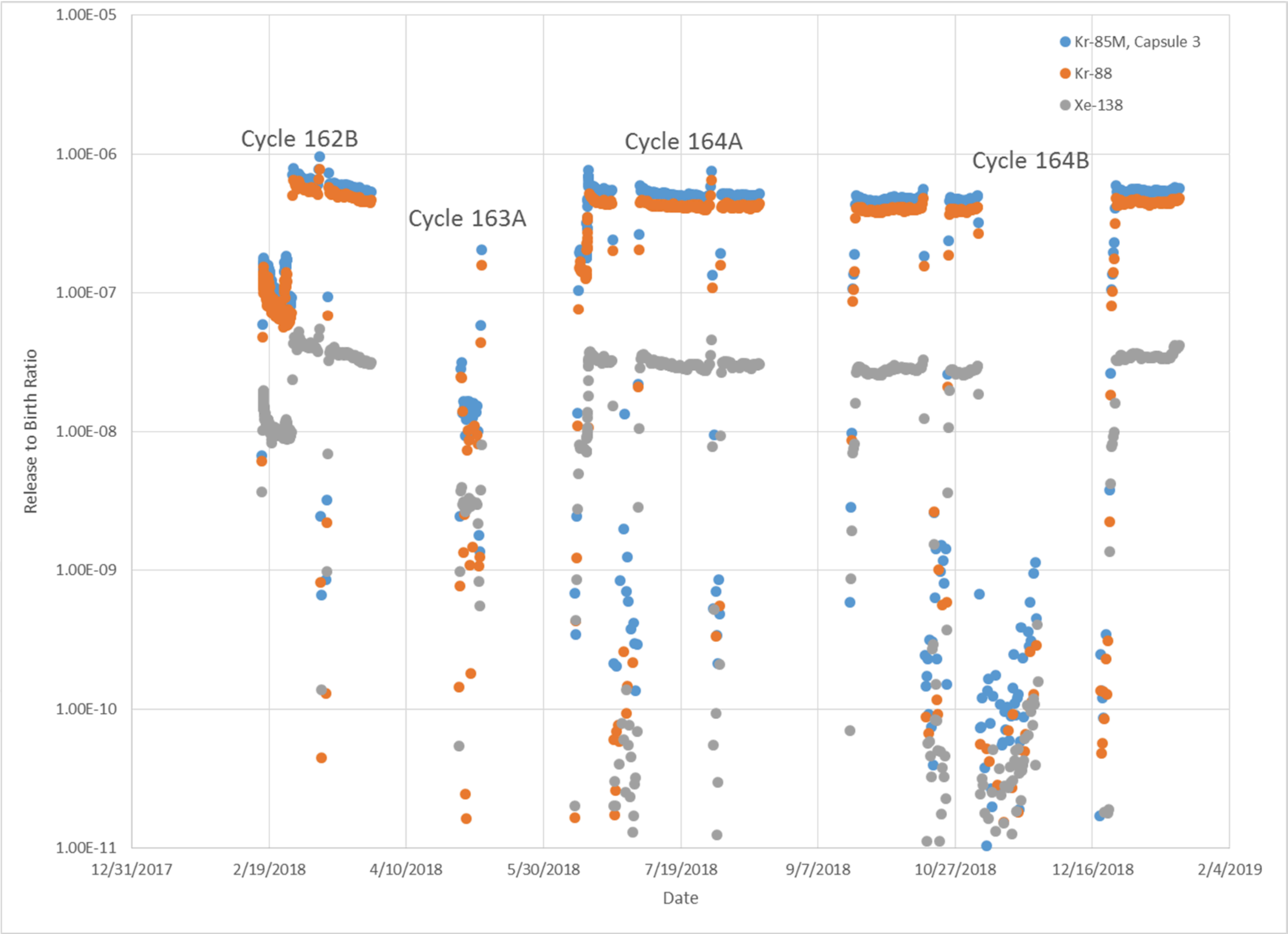
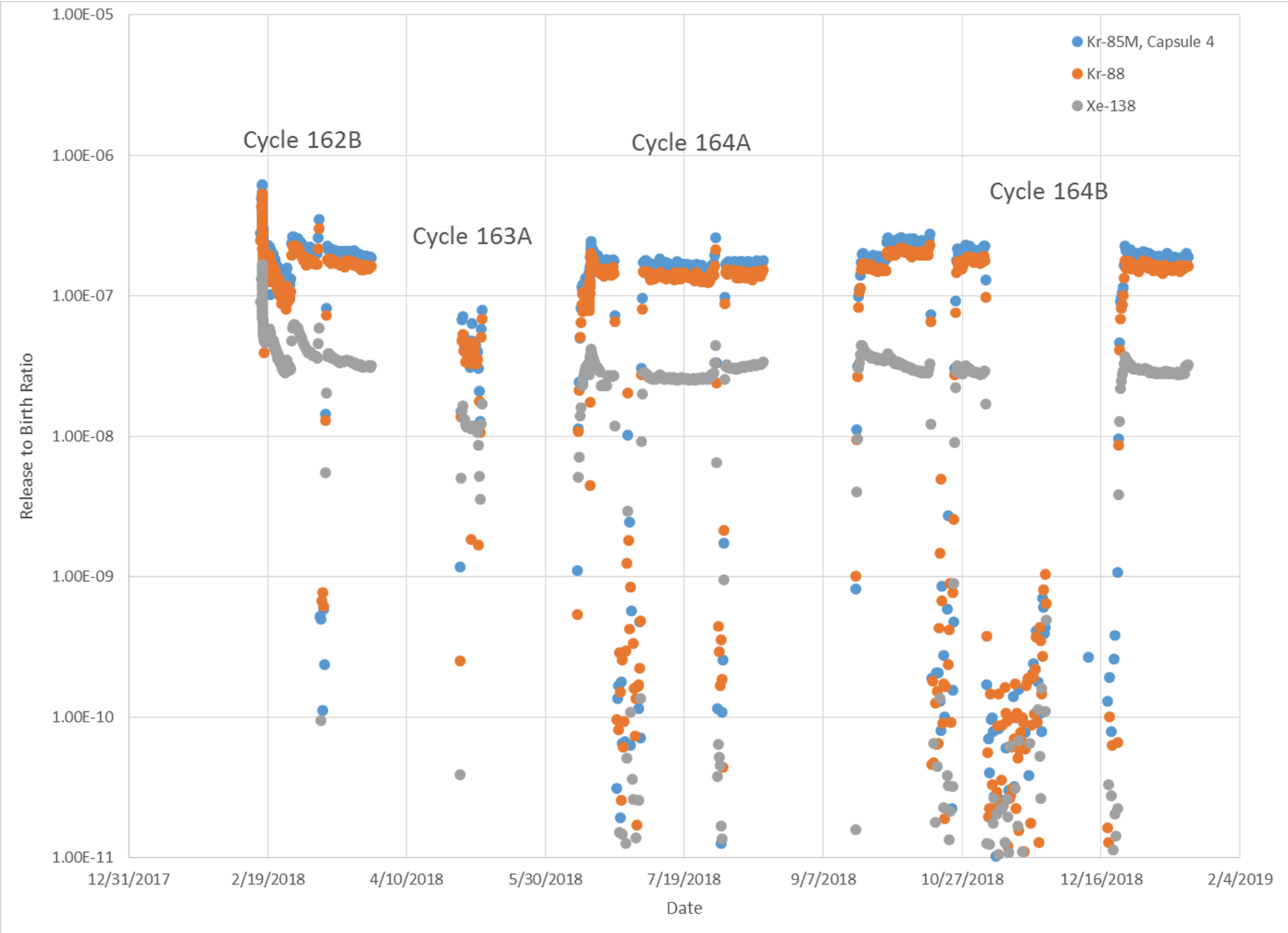
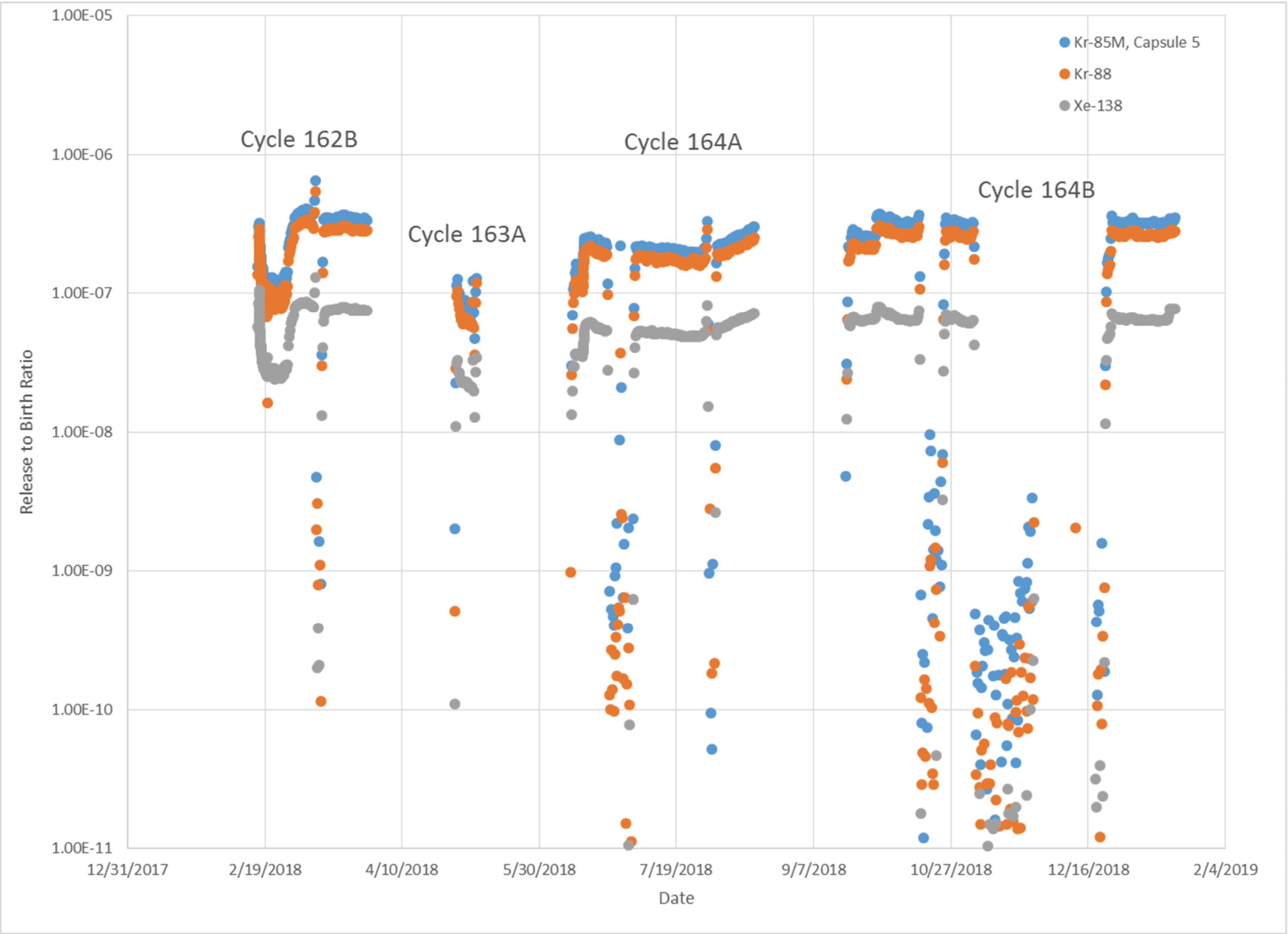


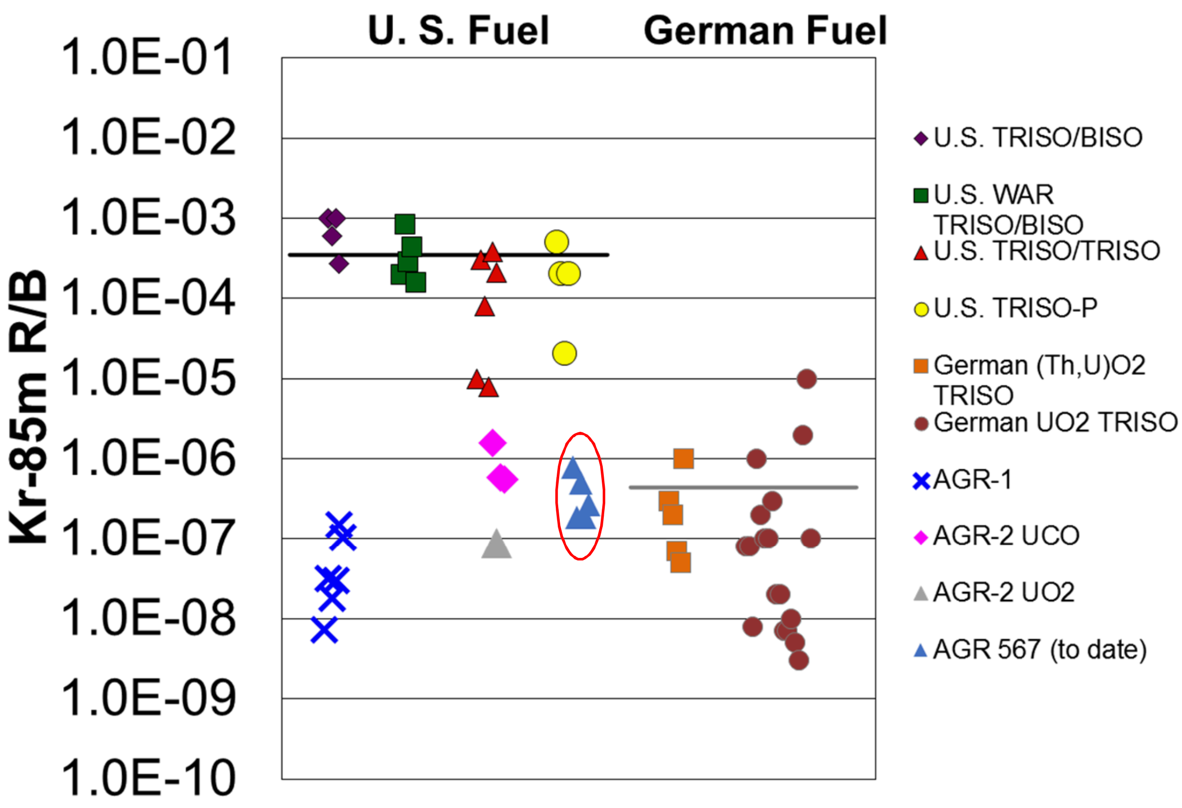
# Preliminary R/B – First Four Cycles- Capsule 4



# Preliminary R/B – First Four Cycles-Capsule 5 (40% PF)



# Preliminary Fuel Evaluation




| | U.S. | German |
|---|---|---|
| **Irradiation temperature ( C)** | **930 - 1350** | **800 - 1320** |
| **Burnup (%FIMA)** | **6.3 - 80** | **7.5 - 15.6** |
| **Fast fluence ($10^{25}$ n/m$^2$ )** | **2.0 - 10.2** | **0.1 - 8.5** |

# Continuing Work

- Daily monitoring of the experiment.
  - Gas Flows
  - Temperature
  - Gaseous Fission Products
- Determine I-135 per cycle
- Continue to improve software
  - Integrate Auto energy calibration
- Evaluate AGR-5/6/7 to past TRISO fuel experiments

# Conclusion

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- AGR-5/6/7 is the fourth and last experiment in the “AGR-experiment” series which is being performed and funded by the United States Department of Energy (DOE) as part of the INL Advanced Reactor Technologies (ART) program.
- The purpose of this experiment is to provide data on fission product migration and retention in the next generation reactor. The design of this experiment is significantly different from the past AGR experiments.
- Larger capsule volumes and an increase in the amount of fuel per capsule impact how gaseous fission products such as longer and shorter lived isotopes of Kr and Xe are transported to the FPMS thus impacting the release activity calculations that are used in conjunction with birth rates as a metric of fuel performance.
- Early R/B indicate that the data may be similar to that of AGR-2.
- As AGR-5/6/7 matures, data and test conditions will be re-evaluated as needed.

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# Thank You!

- Dr. Edward L. Reber
- Dr. Ryan Fronk
- Dr. Julie Bowen
- Thomas Nance
- RML
- ATR LOC

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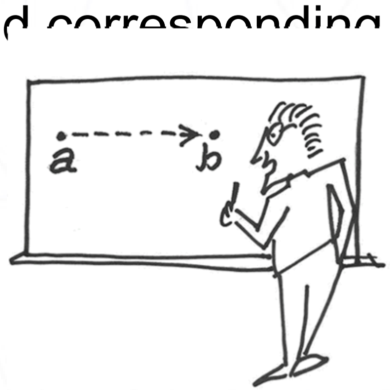
# Additional Slides

# Determination of Transport Volumes – Why?

- To determine fuel performance parameters, fission gas measured at the FPMS must be corrected for decay during the transport time from the constantly – irradiated fuel capsule to the  FPMS measurement location.
- Capsule effluent gas flow rates change according to the desired experimental conditions, it is necessary to define a capsule-to-FPMS transport must be determined so corrections associated with the flow dependent transport time (and corresponding decay) can be made.




Larger capsule volumes and an increase in the amount of fuel per capsule impact how gaseous fission products such as longer and shorter lived isotopes of Kr and Xe are transported to the FPMS thus impacting the release activity calculations that are used in conjunction with birth rates as a metric of fuel performance.

# Determination of Transport Volumes – How?

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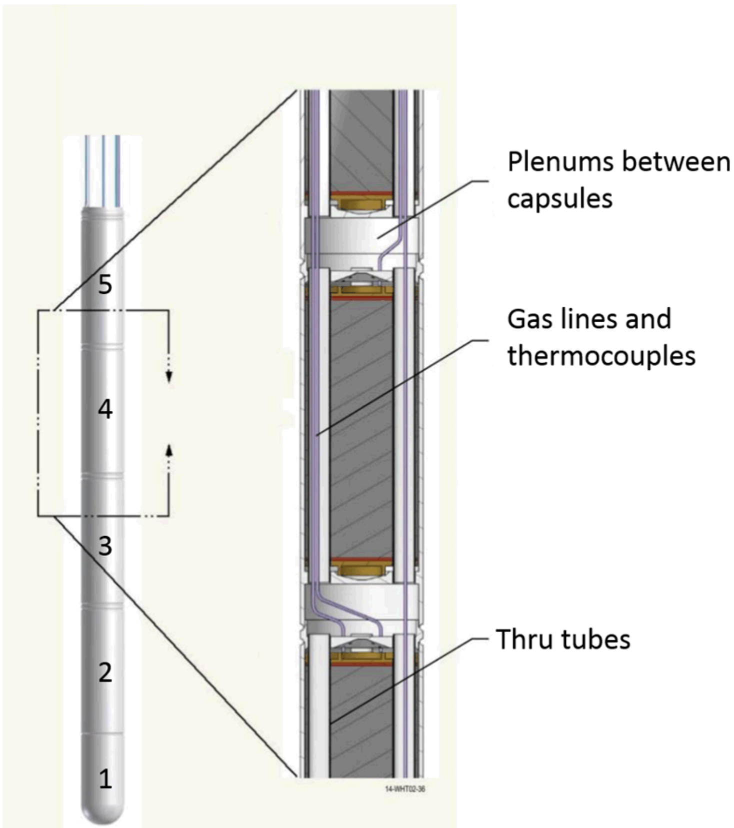



Capsule Train

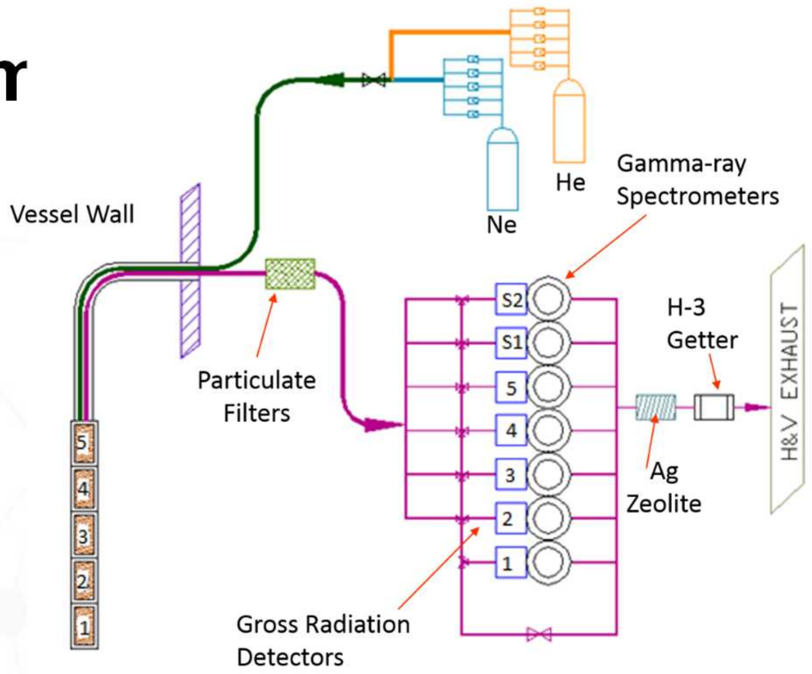
- Five capsules are stacked one on top of the other.
- Instrumentation and gas lines from lower capsules pass through capsules above by means of "thru tubes".
- In the plenum region between capsules there are no thru-tubes therefore required thermocouple and gas lines can be routed into and out of each capsule.
- Leadout tube (not shown) connects capsule train to reactor top head.
- The other end of the leadout bolts to a reactor vessel flange. Thus the leadout acts as a conduit for the various gas lines and leads to enter and exit the ATR reactor vessel.

# How? Continued

- Thermal expansion allowances required that while the thru-tubes could be brazed or welded to the upper capsule heads, the lower closure plates had to be a tightly machined slip fit.
- To ensure that capsule cross talk through the leadout volume did not occur, a helium (He) gas supply is provided to the leadout.
- Gas flows provided to the leadout must exit through the small slip-fit leakage path around the capsule thru-tubes, if the leadout flow rate is adjusted so that all capsules receive some inlet flow from the leadout, capsule cross talk can be eliminated.
- Since there is no thru-tube in capsule one, there should be no cross-talk between capsule 1 and the other capsules.

# Preliminary AGR-5/6/7 Transport Testing/Line Volum

- Measurements acquired from February 23-26, 2018.
- Leadout flow set to 10 sccm Helium.
- Measurements were collected at 3 different total flow set points.
- Volumes are from the top of each capsule to their respective FPM.
- Currently the following isotopes are used in the model: Kr-89, Xe-135m, Xe-137, Xe-138 and Ne-23.
- Values needed to compute release activity.




Capsule to FPM Line Volumes

$V_{t\ capsule\ 1}$ = 240 ± 13 scc

$V_{t\ capsule\ 2}$ = 282 ± 13 scc

$V_{t\ capsule\ 3}$ = 317 ± 07 scc

$V_{t\ capsule\ 4}$ = 293 ± 04 scc

$V_{t\ capsule\ 5}$ = 282 ± 23 scc

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